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Executive Summary for Full-Scale Dual-Alkali Demonstration System at Louisville Gas and Electric Company - Final Design and System Cost

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Interagency Energy/Environment R&D Program Report

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16. ABSTRACT

The report describes phase 2 of a 4-phase demonstration program involving the dual alkali process for controlling SO2 emmissions from Unit 6, a coal-fired boiler at Louisville Gas and Electric Co.'s Cane Run Station. The process was developed by Combustion Equipment Associates, Inc., and Arthur D. Little, Inc. The program consists of four phases: (1) preliminary design and cost estimation; (2) engineering design, construction, and mechanical testing; (3) startup and performance testing; and (4) 1-year operation and test programs. The report describes final engineering design, construction and mechanical testing, and installed system capital cost. Construction of the system was completed in February 1979 and system startup was initiated in March 1979. Total capital investment for the entire plant, including waste disposal, is estimated to be $20.4 million (construction of the waste disposal facilities is not complete).

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by

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APPLICABLE CONVERSION FACTORS
ENGLISH TO METRIC UNITS

British	Metric
5/9 (°F-32)	°C
1 ft	0.3048 meter
1 ft^2	0.0929 $meters^2$
1 ft^3	0.0283 $meters^3$
1 grain	0.0648 gram
1 in	2.54 centimeters
1 in^2	6.452 $centimeters^2$
1 in^3	16.39 $centimeters^3$
1 lb (avoir.)	0.4536 kilogram
1 ton (long)	1.0160 metric tons
1 ton (short)	0.9072 metric tons
1 gal	3.7853 liters
1 Btu	252 calories

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This report was prepared by Arthur D. Little, Inc.; however, the information and data contained in the report represent the work of many individuals from several organizations who have been involved in this project. The principal participating organizations are Louisville Gas and Electric, Inc., Combustion Equipment Associates, Inc., and Arthur D. Little, Inc.

In addition, we would like to acknowledge the efforts and contributions from persons in other organizations. Norman Kaplan, the EPA Project Officer for this demonstration program, has made important technical contributions and has been instrumental in the management of the entire project. Mike Maxwell, the Director of Emissions/Effluent Technology at EPA's Industrial Environmental Research Laboratory, was responsible for overall planning and review of this program and has provided invaluable guidance and support. And Randall Rush of the Southern Company Services has made important contributions of a technical nature to the design of the system.

I. PURPOSE AND SCOPE

A. PURPOSE OF PROJECT

The project covers the full scale application of the Combustion Equipment Associates (CEA)/Arthur D. Little, Inc. (ADL) dual alkali flue gas desulfurization (FGD) system to Unit No. 6, a coal-fired boiler at Louisville Gas and Electric Company's (LG&E) Cane Run Station in Louisville, Kentucky.

The system has been installed on this existing 300 Mw (gross peak capacity) unit to comply with requirements[a] of the Jefferson County Air Pollution Control District, the Kentucky State Division of Air Pollution, and Region IV of the U.S. EPA. EPA selected the dual alkali SO_2 control process at LG&E as a demonstration system for dual alkali technology and is participating in funding of the operation, testing, and reporting of the project.

The dual alkali system has the capability to control the SO_2 emissions to less than 200 ppm dry basis without additional air dilution when burning coal containing up to 5% sulfur. When burning coal containing greater than 5% sulfur, the system will remove at least 95% of the sulfur dioxide in the inlet flue gas. The dual alkali system is not designed for removal of particulate matter; however, it is designed not to increase the loading of particulate matter in the flue gas. As a demonstration system, the purpose of the installation and operation is to establish:

- overall performance - SO_2 removal, lime utilization, sodium makeup, regeneration of spent liquor, water balance, scaling and solids buildup problems, materials of construction, waste cake properties, reliability, and availability.

- economics - capital investment and operating cost.

B. SCOPE OF WORK

The scope of work for the project includes the design, construction, startup, acceptance testing, and one year of operation of a CEA/ADL concentrated mode dual alkali system on Unit No. 6, a 280 Mw coal-fired boiler at LG&E's Cane Run Station. The system is to be designed to treat all of the flue gas emitted at the nominal rated capacity (280 Mw) with the capability for treating flue gas equivalent to a minimum boiler load of 60 Mw and a maximum load of 300 Mw.

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[a]Removal of 85% of the SO_2 present in the flue gas at the scrubber inlet.

LG&E is the prime contractor with overall responsibility for all aspects of the project. CEA, as a subcontractor to LG&E, is responsible for the engineering design, for the supply of all process equipment, and for engineering assistance during startup and acceptance testing. CEA is also responsible for compliance with all process guarantees and equipment warranties. ADL, a subcontractor to CEA, is providing process engineering support to CEA during design, startup, and acceptance testing; and will provide process assistance to LG&E in the operation of the system during the one year test program. ADL is also responsible for the preparation of all reports required under the EPA/LG&E contract.

The work is divided into four phases:

- Phase I - preliminary design and cost estimates;
- Phase II - engineering, design, construction, and mechanical testing;
- Phase III - startup and performance testing; and
- Phase IV - one year of operation and testing.

Baseline testing on the boiler and monitoring of the system performance during acceptance testing and the one year test program is not included as a part of this contract. This work will be carried out by Bechtel National, Inc. under a separate contract with EPA.

This summary covers work performed in Phase II of the project as presented in the Final Design and System Cost report, (EPA-600/7-79-221b, Sept. 1979).

The Final Design and System Cost report describes in detail the plant, as built, and its planned mode of operation. It includes: a description of the process; the operating and control philosophy; material balances and utility requirements; plant layout; a description of major items of process equipment; a description of offsites and auxiliaries; results of the mechanical testing; and actual capital costs for the system.

C. PROJECT SCHEDULE

The overall project schedule covering all phases of the dual alkali demonstration project is given in Figure I-1. The overall project, including the one-year test program, was originally scheduled for 40 months (with an additional one month for completion of the final draft report).

Phases I and II were scheduled to begin simultaneously to expedite the overall project. Phase I (preliminary design) was scheduled for five months including preparation of the draft report. Phase II (engineering design and construction) was scheduled for 24 months starting with the signing of the contract. A detail of the schedule for Phase II is given in Figure I-2.

As indicated in Figures I-1 and I-2, the project has been delayed due to the severe winter of 1977/1978. The project schedule for completion of the project is shown in Figure I-1.

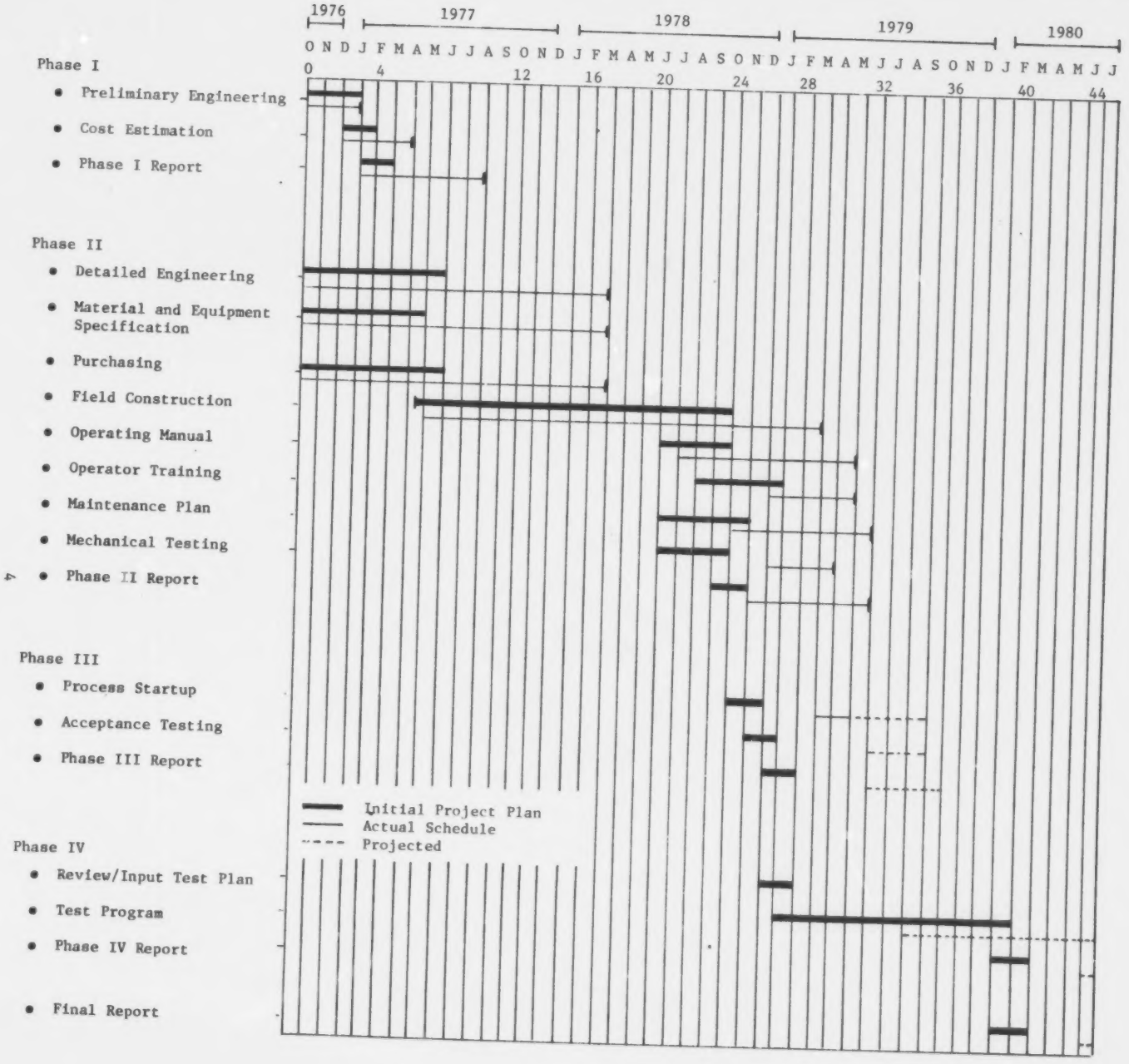

Figure I-1: Dual Alkali Demonstration Overall Project Schedule

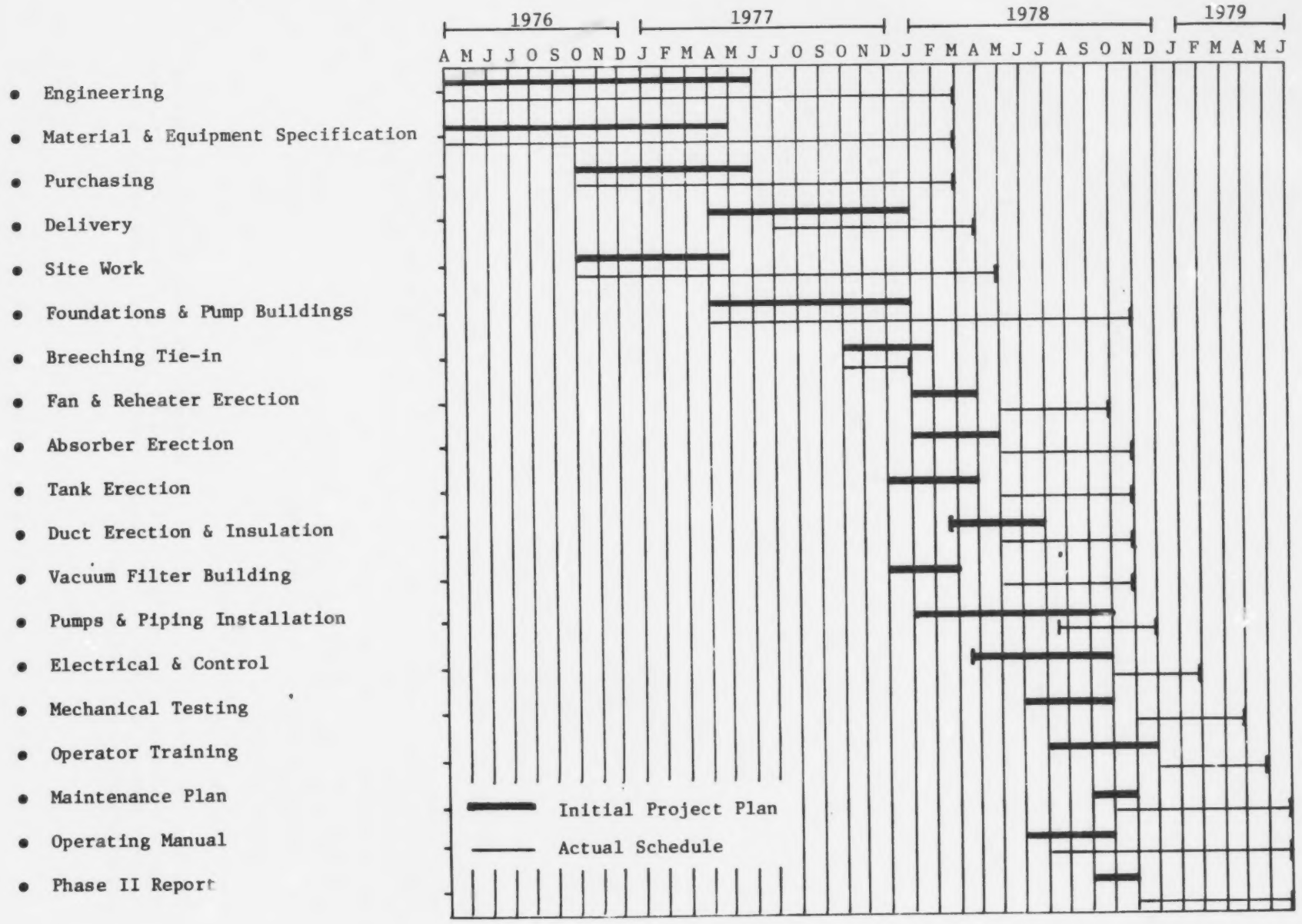

Figure I-2: Phase II Schedule

II. CEA/ADL DUAL ALKALI PROCESS TECHNOLOGY

A. SYSTEM CHEMISTRY AND PROCESS CONFIGURATION

The CEA/ADL dual alkali SO_2 control process involves scrubbing of the flue gas with a solution of alkaline sodium salts. Spent scrubbing solution is regenerated using lime to produce a solid waste consisting principally of a mixture of calcium-sulfur salts.

The system can be conveniently broken down into four processing sections: gas scrubbing; absorbent regeneration; waste solids dewatering; and raw materials preparation. The equipment utilization and operation of each process section depends on specific requirements of the particular application. Figure II-1 shows a generalized flow schematic of a dual alkali process as applied to a boiler equipped with a high efficiency electrostatic precipitator. The following discussion provides a description of the basic system configuration and process flow scheme.

1. Flue Gas Scrubbing

In the generalized system, shown in Figure II-1, flue gas from the electrostatic precipitator (or induced draft fan for the boiler) is forced by a booster fan through an absorber. In the absorber the gas passes upward through a set of sprays to quench the gas, then through a set of sieve trays for SO_2 removal by an alkaline solution, and finally through a demister to remove entrained liquor. The clean flue gas leaving the tower is reheated before being discharged to the stack.

The alkaline solution used to remove SO_2 from the flue gas contains sodium sulfite (Na_2SO_3), hydroxide (NaOH), carbonate (Na_2CO_3), sulfate (Na_2SO_4), and chloride (NaCl). During the process of removing SO_2, the carbonate, hydroxide, and some sulfite are consumed resulting in a spent sodium sulfite/bisulfite liquor. The SO_2 removal process can be represented by the following overall reactions:

$$2Na_2CO_3 + SO_2 + H_2O \rightarrow Na_2SO_3 + 2NaHCO_3 \quad (1)$$

$$NaHCO_3 + SO_2 \rightarrow NaHSO_3 + CO_2\uparrow \quad (2)$$

$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O \quad (3)$$

$$Na_2SO_3 + SO_2 + H_2O \rightarrow 2NaHSO_3 \quad (4)$$

Although the actual reactions within the absorber are more complex, involving various intermediate ionic dissociations, the above set of simplified, overall reactions is an accurate representation of the overall consumption and generation of the various components.

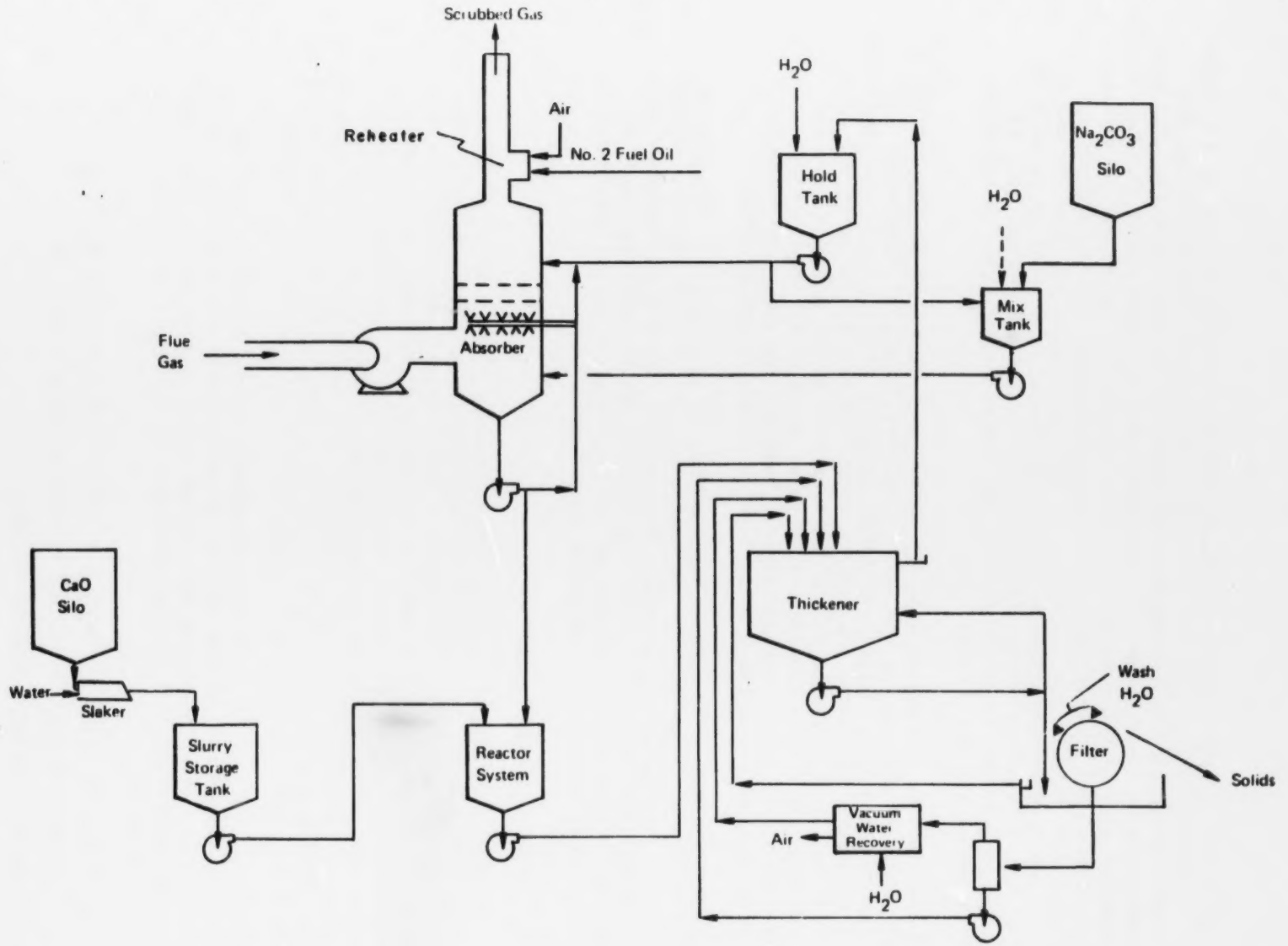

Figure II-1: Dual Alkali Process Flow Diagram

Sodium sulfite plays the most important role in the absorption of SO_2 since it is usually present in the greatest concentration. The hydroxide and carbonate are present in the absorber feed only in small amounts. The concentration of these three alkaline components is a measure of the SO_2 removal capacity of the absorbing liquor. This capacity is conveniently expressed in terms of the "active sodium" concentration where [active sodium] = 2 x $[Na_2SO_3]$ + [NaOH] + 2 x $[Na_2CO_3]$. It must be pointed out that the use of the term "active sodium" is simply one of convenience since it is only an indirect indication of the absorptive capacity of the liquor. SO_2 is actually absorbed by or reacts with the sulfite, hydroxide, or carbonate ions rather than the sodium ion.

Sodium sulfate and sodium chloride do not participate in the SO_2 removal process. In this sense, they are considered "inactive" components. The presence of sodium sulfate and sodium chloride is principally the result of secondary absorption reactions. Sodium sulfate is formed by the oxidation of sodium sulfite via reaction with oxygen absorbed from the flue gas. Oxidation also occurs in other parts of the system where process solutions are exposed to air; however, the amount of oxidation is small relative to the oxidation which occurs in the absorber.

The SO_2 removal efficiency in the absorber is principally a function of the inlet SO_2 concentration, the number of gas/liquid contacting stages, and the pH at which the absorber is operated. For a given scrubber configuration and inlet SO_2 level, SO_2 removal can be adjusted simply by varying the scrubber operating pH. In most utility boiler applications, better than 95% SO_2 removal can be easily achieved.

2. Absorbent Regeneration

A bleed stream from the absorber recirculation loop is sent to the regeneration reactor system where it is reacted with hydrated lime. The CEA/ADL reactor system incorporates a novel design developed to produce solids with good settling and filtration characteristics over a broad range of operating conditions. The reactor system consists of two reactor vessels in series: a short-residence time first stage (3-15 minutes) followed by a longer residence time second stage (30-60 minutes). The process can be operated in conjunction with a lime slaker or can use purchased hydrated lime (e.g., commercial hydrate or carbide sludge).

The lime neutralizes the bisulfite acidity in the scrubber bleed and further reacts with sodium sulfite and sodium sulfate to produce sodium hydroxide. These reactions precipitate mixed calcium sulfite and sulfate solids, resulting in a slurry containing up to 5 wt.% insoluble solids, as shown below:

$$2NaHSO_3 + Ca(OH)_2 \rightarrow Na_2SO_3 + CaSO_3 \cdot 1/2\ H_2O\downarrow + 3/2\ H_2O$$

$$Na_2SO_3 + Ca(OH)_2 + 1/2\ H_2O \rightarrow 2NaOH + CaSO_3 \cdot 1/2\ H_2O\downarrow$$

$$Na_2SO_4 + Ca(OH)_2 \rightarrow 2NaOH + CaSO_4\downarrow$$

The CEA/ADL dual alkali process is designed to operate in a relatively "concentrated" active alkali mode (roughly 0.5M active Na^+ -- where active sodium is defined as that sodium attributable to OH^-, $CO_3^=$, HCO_3^-, $SO_3^=$, and HSO_3^- in solution). In this mode, sulfate removal cannot be effected by precipitation of gypsum ($CaSO_4 \cdot 2H_2O$), since the high sulfite levels prevent soluble calcium concentrations from reaching levels required to exceed the gypsum solubility product. Thus, the system operates unsaturated with respect to calcium sulfate, thus minimizing scale potential. However, calcium sulfate is coprecipitated with calcium sulfite in the regeneration reactor, which allows the system to keep up with absorbent oxidation.

3. Solid/Liquid Separation and Solids Dewatering

Slurry from the regeneration reactor system is fed to a thickener where the slurry is concentrated to 20 to 45% solids. Clarified liquor from the thickener is collected in a hold tank from which it is returned to the absorber. The thickened slurry is sent to rotary drum vacuum filters, where the solids are filtered to a cake containing 55 to 70% solids. The filter cake is the only waste material generated by the process. There are no other solid or liquor purges from the system.

The high solids content of the filter cake and the excellent handling properties of the material are a direct result of the controlled conditions for crystallization in the reactor system. The material is much like a moist silty to sandy soil and is easy to manage in solids handling and transport equipment. If further chemical treatment is required, these excellent physical properties should prove to be an advantage.

On the filter the cake is washed using a series of water spray banks. This wash removes a large fraction (approximately 90%) of the occluded soluble salts from the cake and returns these salts along with the filtrate to the system, thereby reducing sodium losses and minimizing sodium carbonate makeup.

The exact chemical composition of the solids will depend somewhat upon fly ash loading (if any), the chemical composition of the flue gas and fly ash, and the degree of oxidation of sulfite to sulfate encountered in the system. The following general chemical composition (ash-free, dry cake basis) is typical for a high sulfur coal application:

$CaSO_3 \cdot 1/2\ H_2O$	= 80-85 wt.%
$CaSO_4 \cdot 1/2\ H_2O$	= 10-15 wt.%
$Na_2SO_4 + Na_2SO_3 + NaCl$	= 1-3 wt.%
$CaCO_3$ + Inerts	= 5-10 wt.%

The mix of sodium salts in the cake is importantly dependent upon the chloride content of the coal. Essentially all of the chloride in the coal is released to the flue gas as HCl gas, and it is efficiently removed in the absorber. The chloride is purged from the system in the filter cake (as NaCl) at the rate at which it is absorbed. Thus, the higher the chloride content of the coal, the higher the fraction of sodium salts as sodium chloride.

4. Raw Materials Preparation

The operation of the dual alkali system requires the addition of lime for absorbent regeneration and of sodium carbonate to make up for the sodium lost in the occluded liquor in the waste cake.

Typically, lime would be slaked and hydrated prior to being fed to the reactor system. Alternatively, commercial hydrated lime or carbide sludge could be fed directly to the reactor system.

The sodium carbonate solution can be prepared either with clarified liquor from the thickener or with fresh water. Makeup sodium carbonate solution is fed to the system to replace sodium value lost in the filter cake. The sodium carbonate is not intended for use as a softener, since soluble calcium concentrations in the regenerated liquor runs less than 100 ppm. The quantity of sodium carbonate required, therefore, is quite small, and the sodium carbonate costs represent a negligible element in the overall cost of operating the system.

B. POLLUTION CONTROL CAPABILITIES

1. SO_2 Control

A sodium-based dual alkali process, operating in the concentrated active sodium mode, is capable of SO_2 removal efficiencies in excess of 95% and almost any range of inlet SO_2 concentrations encountered in coal-fired utility boiler applications. In most high sulfur coal applications, removal efficiencies approaching 99% can be achieved on a continuous basis in low-energy, tray-type absorbers[1]. SO_2 removal efficiencies can be easily varied by adjusting the operating pH of the absorber with little or no effect on the overall lime stoichiometry or the sodium makeup requirement.

The high SO_2 removal capability of this process, when used in conjuction with a boiler equipped with adequate control of particulate matter, allows the option of removing virtually all of the SO_2 from the flue gas treated in the scrubber. Thus, there is the option of bypassing hot, untreated gas to provide part or all of the reheat while still meeting the overall

[1]LaMantia, C.R., et al., "Final Report: Dual Alkali Test and Evaluation Program," Volume III, EPA Contract 600/7-77-050, May 1977.

plant SO_2 emission regulations in the combined treated and untreated flue gas. In such a system, the scrubber size can be reduced, since not all flue gas is treated. Also, reheat requirements are reduced or eliminated. In the system for Cane Run Unit No. 6, bypass for reheat is not provided. All of the flue gas will be treated with reheat provided by injection of hot gas from the combustion of No. 2 fuel oil.

2. Control of Particulate Matter

While the dual alkali system at the Cane Run Station is not designed to remove particulate matter, this capability can be accommodated in the process by appropriate selection of the type of scrubber system to be used. If particle removal is to be performed by the system, then a higher energy particulate matter removal device, such as a venturi scrubber, would be required. This scrubber alone can be used for both SO_2 and particulate control; or, if additional SO_2 removal is required (>95%), a venturi can be used in combination with one or more trays at a small incremental cost. Removal of particulate matter down to 0.02 grains/scfd or lower can be accomplished using venturi scrubbers at moderate pressure drops (about 20 inches WG).

Where particulate matter control is already provided ahead of the scrubber system, the SO_2 scrubbing system will not result in any increase in particulate emissions. Because a solution is used for SO_2 absorption rather than a slurry, any entrainment of scrubbing solution in the gas can be efficiently and reliably removed using standard mist eliminators without wash water prior to exhausting the gas.

3. Chloride Control

Most of the chloride in coal (>90%) is volatilized and appears in the flue gas as HCl. Any aqueous-based scrubbing system would be highly effective in absorption of HCl (as well as HF) from the flue gas. As a result, chloride concentrations will build in the closed liquor loop to levels such that the rate at which chloride is discharged from the system in the washed filter cake will equal the rate at which chloride enters the system with the flue gas. The CEA/ADL dual alkali system has been successfully operated for extended periods with steady-state levels of chloride in the closed liquor loop as high as 11,000 ppm (consistent with 0.05-0.10 wt.% chloride in the coal)[1].

[1] Ibid.

III. DESCRIPTION OF THE DUAL ALKALI PROCESS APPLICATION AT THE CANE RUN STATION

This chapter provides a description of the application of the dual alkali technology to the specific flue gas desulfurization requirements for LG&E's Cane Run Unit No. 6. In designing the system, consideration was given to the sources, characteristics, and amounts of flue gas to be cleaned as well as to the type and sources of the required raw materials.

A. SYSTEM DESIGN

1. Design Basis

Cane Run Unit No. 6 consists of a pulverized coal-fired steam boiler, built by Combustion Engineering, with a Westinghouse turbine-generator. The unit operates from a minimum of 60 Mw during off-peak hours to a maximum load of 300 Mw during peak hours. The annual average load is equivalent to approximately 180 Mw (about 60% of the gross peak capacity). The boiler is equipped with a high efficiency electrostatic precipitator capable of 99.4% particulate matter removal. The dual alkali system for Cane Run Unit No. 6 is designed for SO_2 removal only.

Coal for Unit No. 6 is received from a number of sources. The average sulfur content on a dry basis is 4.8% and varies from 3.5% to 6.3%. The average chloride content of the coal is 0.04% and varies from 0.03% to 0.06%. The average 4.8% sulfur content and 11,000 Btu/lb will result in an SO_2 emission level equivalent to about seven times that allowed by the present Federal New Source Performance Standards (1.2 lbs of SO_2/MM Btu).

The design basis for the dual alkali system is summarized in Table III-1. Design conditions correspond to coal containing 5% sulfur and 0.04% chloride and having a heating value of 11,000 Btu/lb on a dry basis. The design gas capacity of 3,372,000 lbs of flue gas per hour (combined flow to both scrubbers) corresponds to the boiler peak load capacity of 300 Mw.

The dual alkali system is designed to meet all applicable federal, state, and local pollution control and safety regulations. The maximum SO_2 concentration in the scrubbed gas will be 200 ppm (for coal containing up to 5% sulfur), well below requirements of the current NSPS. There will be no discharge of process liquor from the system; and the disposal of the waste solids produced will meet all applicable federal, state, and local solid waste disposal regulations currently in effect. None of the wastes will be discharged to or allowed to enter any naturally occurring surface water. Plans for disposal are discussed as a part of this report.

TABLE III-1

DUAL ALKALI PROCESS DESIGN BASIS

Coal (Dry Basis):	
Sulfur	5.0% S
Chloride	0.04% Cl^-
Heat Content	11,000 Btu/lb
Inlet Gas:	
Flow Rate (Volumetric)	1,065,000 acfm
(Weight)	3,372,000 lb/hr
Temperature	300°F
SO_2	3471 ppm (dry basis)
O_2	5.7 vol %
Particulate Matter	$\leq$0.10 lb/10^6 Btu
Outlet Gas:	
SO_2	$\leq$200 ppm (~0.45 lb/10^6 Btu)
Particulate Matter	$\leq$0.10 lb/10^6 Btu

2. Guarantees

The process guarantees listed below include minor revisions since publication of the project manual containing the preliminary design and cost estimate (EPA-600/7-78-010, January, 1978).

a. Sulfur Dioxide Emission

The system shall provide such control that emissions from the stack shall be no greater than 200 ppm by volume SO_2 dry basis not including SO_2 added from the operation of the reheaters and without additional air dilution when burning the coal containing less than 5% sulfur. When burning coal containing 5% sulfur or greater, the system shall remove at least 95% of the sulfur dioxide in the inlet flue gas.

b. Particulate Matter Emission

In addition to meeting applicable regulations, the system shall also meet Federal New Source Performance Standards for emissions of particulate matter under all conditions of boiler operation. The dual alkali system shall not add any particulate matter to the emissions of particulate matter that is received by the system from the LG&E Cane Run Unit No. 6 electrostatic precipitator.

c. Lime Consumption

The consumption of lime in the system shall not exceed 1.05 moles of available CaO in the lime feed per mole of SO_2 removed from the flue gas.

d. Sodium Carbonate Makeup

Soda ash makeup shall not exceed 0.045 moles of Na_2CO_3 per mole of SO_2 removed from the flue gas provided that the chloride content of the coal burned averages 0.06% or less. If the average chloride content of the coal is above 0.06%, then additional sodium carbonate consumption will be allowed at the rate of 1/2 mole Na_2CO_3 for each mole of chloride (Cl^-) in the flue gas resulting from chloride in excess of 0.06% in the coal. The Seller as part of the guarantees shall perform the necessary research and design to reduce the makeup requirements of N_2CO_3 from the guarantee point to a level approaching minimal makeup.

e. Power Consumption

At the peak operating rate (300 Mw), the system shall consume a maximum of 1.2% of the power generated by the unit.

f. Waste Solids Properties

The waste produced by the vacuum filter shall contain a minimum of 55% insoluble solids.

g. SO_2 System Availability

The system shall have an availability (as defined by the Edison Electric Institute for power plant equipment) of at least 90% for one year. Thus, the system shall be available for operation at least 90% of the calendar time.

3. Process Description

The system configuration and operation will differ slightly from the generalized process discussed previously. The principal difference is that the system will utilize locally available carbide lime, a calcium hydroxide byproduct from acetylene production, rather than slaked quicklime.

The system design is modular in nature, with spare capacity provided both as excess capacity within modules as well as spare modules and equipment where appropriate. Redundant instrumentation has also been provided for critical control operations.

a. Absorber Section

The absorber section consists of two identical scrubber modules. Each module is made up of a booster fan, an absorber, an oil-fired flue gas reheater, and two recirculation pumps (one operating and one back up).

Flue gas is drawn from the existing induced draft fans and is forced through the absorbers by means of the booster fans. The basic design and control philosophy is predicated on both absorbers operating simultaneously with each handling half the boiler load. However, during periods of low boiler load, one absorber is capable of handling all of the gas. Hence, in order to allow for greater flexibility in operation and provide for the possibility of allowing maintenance on one module while the system is still in service, a common duct connecting the two booster fan inlets has been incorporated. A bypass is also provided to allow complete shutdown of the scrubbers while the boiler is still on line. The bypass and FGD system inlet dampers have been properly interlocked to enable bringing the absorbers on- or off-line without interruption of the boiler operation.

Hot flue gas ($\sim$300°F) entering each absorber is first cooled by a set of sprays which direct scrubbing solution at the underside of the bottom tray. In addition to providing temperature control at the bottom of the absorbers, these sprays keep the underside of the tray and the bottom of the absorber free of any buildup of fly ash solids. The cooled, saturated gas passes through a set of two trays where SO_2 is removed and then through a chevron-type demister. After leaving the absorber, the scrubbed gas is reheated 50F° (to a temperature of about 175°F) by mixing it with hot flue gas from oil-fired reheater to avoid condensation and corrosion as it is exhausted to the stack.

The scrubbing solution which flows counter-current to the gas is collected at the bottom of the absorber. This liquor is used for the quench sprays and as a recycle stream to the top tray for pH control. Since the scrubbing solution is regenerated with lime, the feed to the absorber contains sodium hydroxide and therefore is very alkaline. A high tray feed pH increases the absorption of CO_2 which in turn increases the potential for $CaCO_3$ scaling in the absorber. The recycle also ensures proper liquid loading on the trays. A bleed stream from the bottom of the absorber is sent to the reactor system for regeneration to an active sodium solution. Provisions have been made for an automatic emergency water supply to spray and quench the hot flue gas in the event that the recycle pump fails.

b. Reactor Section

This section of the system consists of two identical reactor trains each containing a primary and secondary reactor.

At operation under design conditions, each reactor train would handle the regeneration of solution from the corresponding absorber; although for short periods of time, a single reactor train is capable of handling the solutions from both absorbers operating at design conditions. When the boiler is firing typical or average coal (3.5-4.0% sulfur), only one reactor train is normally required.

The spent scrubbing solution is introduced to the primary reactor along with slurried carbide lime from the lime day tank. The slurry from the secondary reactor is fed to the thickener feed well where the separation of the regenerated solution from the solid waste is initiated.

c. Solids Dewatering

The reactor effluent, a slurry containing 2-5% insoluble solids, is directed to the feed well of the thickener. The thickener is generally operated to provide an underflow (thickened) slurry containing about 25 wt % solids. The thickener underflow slurry is recirculated past the filters in a recycle loop that returns the slurry to the solids zone of the settler. A bleed from this recirculation loop is fed to the filters. Each filter is equipped with an overflow pipe returning to the solids zone in the thickener to allow for operation in an overflow mode and thereby provide against inadvertent overflow of the filter hold tank.

There are three filters, each rated to handle 50% of the total solids produced at the design conditions. Each filter can be operated independently. The number of filters in operation is determined by the quantity of solids accumulated in the thickener, which is reflected in the solids concentration in the underflow slurry and the position of the thickener rake lift indicator. For operation at typical conditions (3.5% S and an average daily load of 60-70%), it is anticipated that only 2 filters need to be operated about one shift per day.

The solid cake is washed on the filter using a series of water spray banks. This wash removes a large fraction (approximately 90%) of the occluded soluble salts from the cake and returns these salts to the system, thereby reducing sodium losses and minimizing sodium carbonate makeup.

Clear liquor overflow from the thickener is collected in the thickener hold tank which both provides surge capacity for the absorbent liquor feed to the scrubber system and maintains overall control of the volume of liquor in the system. Water is added to this hold tank to make up for the difference between total system water losses (evaporation and cake moisture) and total water inputs from other sources (sodium makeup solution, pump seals, lime feed, and cake wash).

d. Raw Materials Preparation

Two chemicals are required for the operation of the dual alkali system: lime for absorbent regeneration and soda ash to make up for sodium losses.

Carbide lime, a byproduct of acetylene production, is available to LG&E at a significantly lower price than commercial lime. The carbide lime is barged to the Cane Run Station as a slurry containing approximately 30% insoluble solids. From the main storage tank, the lime slurry will be pumped to a grinding system consisting of a hydroclone and wet ball mill to prevent feeding of oversized material. From the grinding system, the lime will be pumped to the dual alkali system day tank which supplies lime to the primary reactor at the appropriate rate. Since installation of the grinding equipment has been delayed beyond the startup date for the dual alkali system, a disintegrator with coarse screens has been temporarily installed upstream of the day tank for rough sizing of the raw carbide lime until the permanent grinding facility is completed.

The addition of sodium carbonate to the system is to compensate for the losses of sodium in the cake. Despite washing the cake, some liquor, containing soluble sodium salts, will inevitably remain occluded in the cake.

Dry, dense soda ash is received at the plant and stored in the soda ash silo from which it is fed to the soda ash solution tank by means of a weigh feeder. Soda ash solution can be made up using either clarified liquor drawn from the thickener hold tank or fresh water. Provisions have also been made to feed the soda ash solution either directly to the absorbers or to the thickener. The normal mode of operation is to prepare the soda ash makeup solution using clarified liquor and to feed it to the absorbers.

e. Waste Disposal

A long-range plan for the disposal of the dual alkali filter cake has been developed as a part of an overall disposal plan for all FGD wastes produced at the Cane Run Station. The plan involves stabilization of the wastes generated by each of the three FGD systems via the addition of lime and fly ash and dry landfill of the stabilized material adjacent to the plant. Waste from the dual alkali system on Unit No. 6 will be handled, processed, and disposed of independently of the wastes produced by the direct lime scrubbing systems on Unit Nos. 4 and 5. Wastes from these latter two units will be combined and handled in a common processing plant.

Installation of the waste processing plant is scheduled for completion in the fall of 1979. In the interim, the filter cake conveyor will discharge through a feed chute directly into trucks which will transport the waste to a temporary storage area. Once the processing plant is operational, this waste will be reclaimed from the storage area and processed along with fresh filter cake.

f. Provisions for Spills and Leaks

Filter cake is the only product of the dual alkali system. The system will be operated in a closed loop and there will be no other solid or liquid discharge from the system. In order to avoid inadvertent discharge of any process liquor, provisions have been made in the process design. All pump and piping flush water, pump seal water leaks, and equipment and building wash down water is collected in sumps and returned to the system.

The thickener and thickener hold tank have a combined surge capacity equivalent to the total capacity of all process vessels in the system. The additional capacity was incorporated in the system to allow for temporary storage of liquor from other process vessels and to prevent any short-term spills of liquor due to water imbalances resulting from extreme process upsets. In addition, the thickener hold tank is equipped with an emergency overflow tank which will begin to fill when extreme levels have been reached in the thickener and hold tank.

4. Operating Requirements

System operating requirements at design conditions are summarized in Table III-2. The power required to operate the process (exclusive of reheat) will be approximately 1% of the peak power generation for Unit No. 6. Of this, approximately 60% is required for the booster fans, 10% for reheater fans, and 30% for the remainder of the system. Including oil for reheat, the total energy requirement for the system amounts to about 2.7% of the peak power generation.

TABLE III-2

PROCESS OPERATING REQUIREMENTS AT DESIGN CONDITIONS

Basis: Coal - 5.0% sulfur
- 0.04% chloride
- 11,000 Btu/lb

Full Load (300 megawatts)
FGD Inlet SO_2 - 390 lbs/min
SO_2 Removal - 94.4%

	Consumption Rate	Equivalent % of Boiler Capacity
Energy Requirements		
Power	3.1 megawatts	1.03
Fuel Oil (for reheat)	48 x 10^6 Btu/hr	1.68
		2.7
	Consumption Rate	**lbs/lb Coal Fired**
Makeup Materials		
Water	450 gpm	---
Lime (as $Ca(OH)_2$)	460 lbs/min.	0.111
Soda Ash	13.7 lbs/min.	0.003
Cake Production		
Dry Basis	804 lbs/min.	0.194
Wet Basis	1,246 lbs/min.	0.300

The lime and soda ash makeup requirements correspond to feed stoichiometries of 1.0 moles $Ca(OH)_2$ per mole of SO_2 removed and 0.022 moles Na_2CO_3 per mole of SO_2 removed. These feed requirements include the alkali needed for chloride removal. The total wet cake produced is equivalent to 30 lbs of moist filter cake per 100 lbs of coal (5% sulfur) fired.

B. DUAL ALKALI PLANT CONFIGURATION AND EQUIPMENT

1. Plant Layout

Cane Run Unit No. 6, the last and largest of six boilers at the Cane Run Station, is located at the north end of the plant complex. A photographic overview of the north end of the plant in Figure III-1 shows the boiler/turbine house, the two parallel electrostatic precipitator sections and exhaust stack of Unit No. 6 and the dual alkali facility. The two SO_2 absorbers have been installed behind the precipitators one on each side of the stack. The chemical plant consisting of the reactor system, dewatering equipment, and raw materials preparation areas are sited north of the boiler and scrubbers.

The building shown behind the thickener houses the filters and associated filtration equipment; the reactor, lime feed, and hold tank pumps, and the system sumps. The two reactor trains are located next to and are accessed from the filter building. The soda ash silo and soda ash solution tank are located in the north-east corner of the facility, adjacent to the thickener in the foreground of Figure III-1. The thickener overflow tank is located between the thickener and the filter building; and the lime feed day tank is located behind the filter building.

The relative location of the reactor trains and the lime slurry tank is shown in more detail in Figure III-2. The elevation of the primary reactors, secondary reactors, and thickener is designed to allow operation of the regeneration system completely in an overflow mode.

2. Materials of Construction

The system is designed with appropriate corrosion resistance where required using stainless steel (316 or 317) or linings (polyester or rubber). The expected chloride levels in the process liquor range from 10,000 ppm to 15,000 ppm, but levels can vary from as low as a few thousand ppm to almost 20,000 ppm depending upon the chloride content of the coal and the degree of cake washing. Liquor pH's range from about 5.0 in the absorber loop to greater than 12.0 in the reactor and dewatering systems.

With the exception of the primary reactors, all tanks and vessel linings in contact with process liquor are lined with flake-reinforced polyester. The primary reactor is constructed of 316L stainless steel; the filtration equipment is both 317L stainless steel and fiberglass; and the absorber trays are 317L stainless steel.

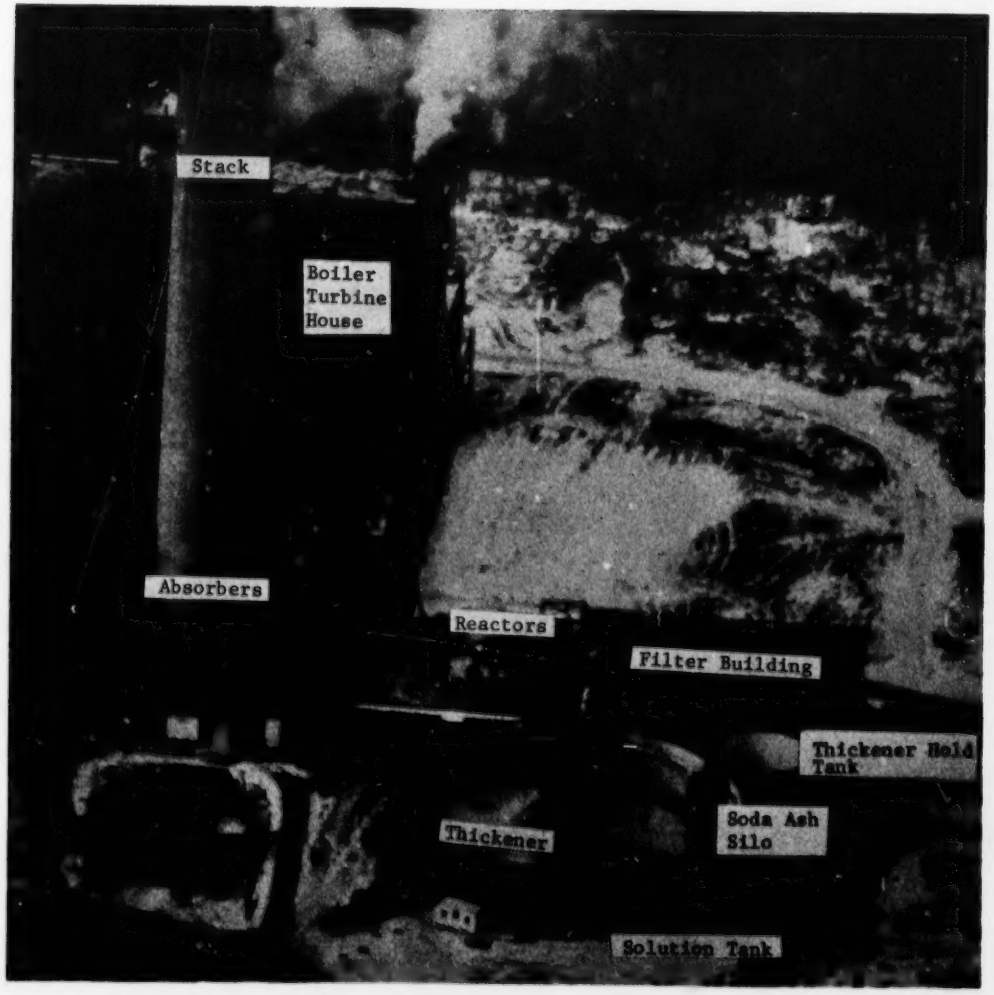

Figure III-1: Overall View of Cane Run Unit No. 6 and the Dual Alkali System

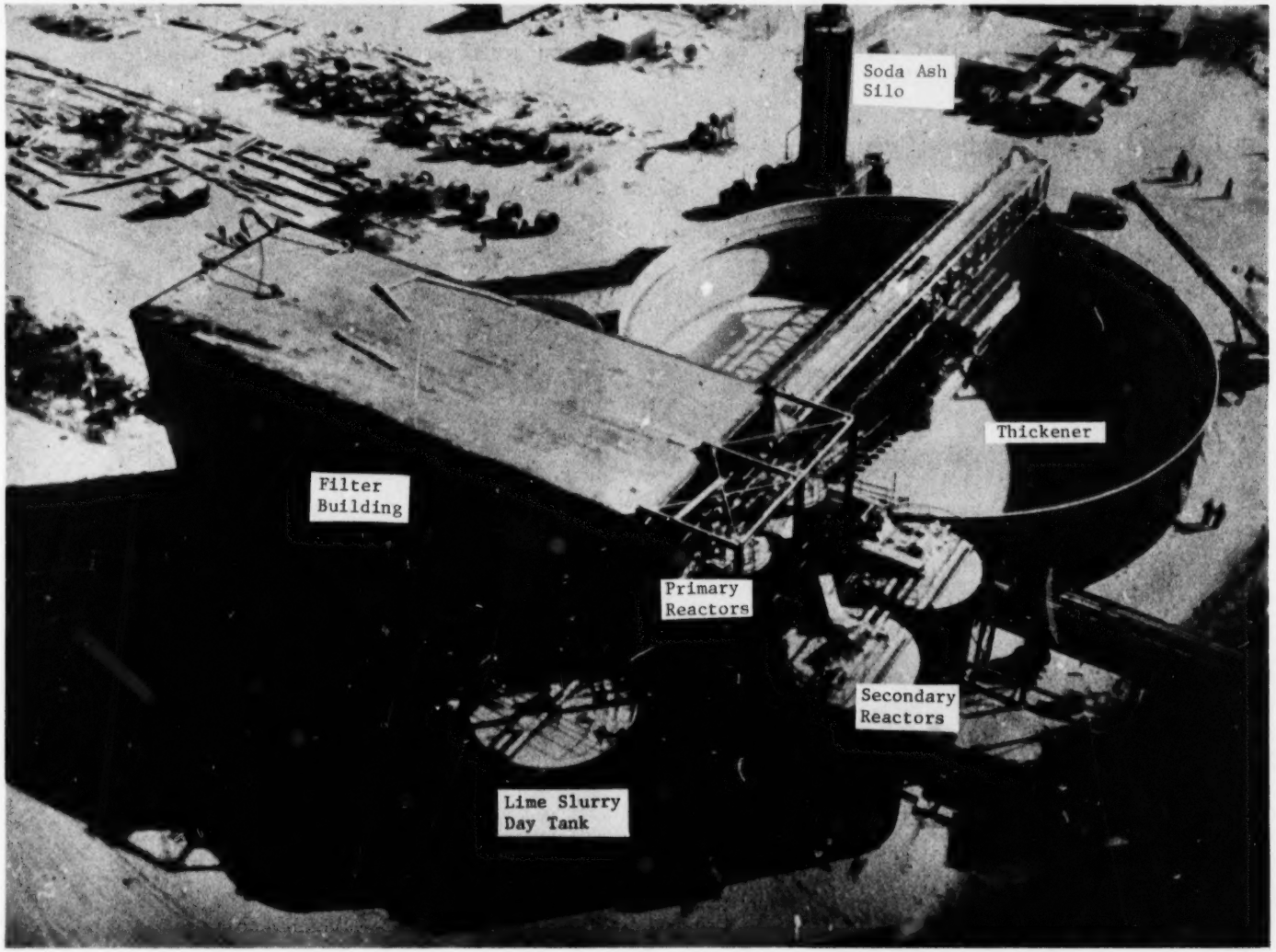

Figure III-2: Overall View of the Chemical Plant

All pumps and agitators in contact with process liquor are rubber-lined. Process liquor piping is FRP. Hot flue gas ducting is carbon steel, and the booster fan housing and blades are A441 steel. Saturated flue gas ducting is polyester-lined between the absorbers and reheater section and is 317L stainless steel between the reheater and stack.

3. Instrumentation

The system is designed for minimal operator interface consistent with safe and reliable operation. Feed rates for all raw materials and the flows of all principal process streams are automatically controlled according to process operating conditions (tank liquid levels, process flows, and stream compositions). Non-critical internal process flows are preset and adjusted intermittently as dictated by process requirements.

All remote controls are located in a centralized control room from which the system can be started up, operated, and shut down. The control room is furnished with appropriate controllers, indicators, recorders, alarms, and other necessary instrumentation for the safe and convenient operation of the system.

Redundancy has been provided in critical control elements to ensure smooth operation and minimize downtime. Instrumentation in addition to that required to operate the process has also been provided to permit accurate calculation of process material and energy balances. In particular, instruments are included for continuous monitoring of inlet and outlet SO_2 concentrations, the measurement of all chemicals and water entering the system, and the weighing of all filter cake leaving the system.

4. Offsites

The offsites required for the dual alkali system include: services for electrical supply, water supply, and instrument air; oil for reheating the saturated flue gas; raw materials receiving and storage facilities; a wet chemicals analytical laboratory; and appropriate shop facilities for repair and maintenance of machinery and instruments. Except for electrical service, all of these offsites including lime receiving and storage facilities, existed at Cane Run Station and are available. An electrical substation including appropriate step-down transformers has been installed for the dual alkali system.

C. MECHANICAL TESTING OF EQUIPMENT

Mechanical testing of the dual alkali system began in December, 1978 and concluded in March, 1979. Start-up operations were initiated in early March. In general, the mechanical testing consisted of checking the tanks for leaks and inspecting the internal linings; checking and operating the pumps and agitators; flushing all lines; zeroing and checking the instrumentation for proper operation. Additional tests were carried out on equipment which serve special functions. In the absorber section, these

tests involved checking and operating the booster fans, the gas reheaters, the dampers as well as checking the ductwork. The flow distribution in the absorber trays and the operation of the absorber sprays was also checked. In the dewatering section, the thickener rake, its driving and lift mechanisms were checked and operated. For the filters, the drum and tub agitator drives, the vacuum pumps, and the blow-back fans were checked and operated. For the soda ash silo, the vibrating bin, the dust collector and weigh feeder were checked and operated.

In general, the individual pieces of equipment performed well during the testing period. Corrective measures, however, were required for the following items:

- Booster fans - Shaft gap corrections were needed in the fluid drives and the booster fan speed controller was modified.

- Dampers - The gear boxes in the outlet dampers had to be replaced. The blades in the inlet dampers had a tendency to drift apart. This problem was caused by defective motor brakes. The possibility of providing additional seals for the dampers to further reduce gas leakage is currently being considered.

- Pumps - The large capacity of the reactors and thickener underflow pumps caused excessive chatter and vibration. The pumps were slowed down to the required range by changing the pump sheaves.

- Agitators - The excessive amount of current drawn by the agitators was reduced by trimming the edges off the impellers. At the same time, the impeller arms were reinforced to minimize flexing.

- Valves - Two butterfly valves in the absorber recirculation loop failed and had to be replaced by heavy duty butterfly valves.

- Lime slurry supply - As previously indicated in the raw materials section, a hydroclone-ball mill grinding system will be installed to prevent feeding of oversized material. As a temporary measure, a disintegrator was installed in the lime supply system.

- Soda ash make-up - During loading of the system with soda ash, warm vapor from the solution tank caused crystallization of the soda ash on the feed chute to the solution tank. A blow-back fan was installed to prevent the vapors from entering and plugging the chute.

IV. CAPITAL COSTS FOR THE DUAL ALKALI SYSTEM AT THE CANE RUN STATION

The installation of the dual alkali system at Cane Run Station Unit No. 6 required capital investment in three different facilities: the flue gas desulfurization (FGD), the lime slurry feed system, and a waste processing and disposal system. Each of these facilities has involved independent design and installation efforts, and their costs are reported separately. While construction of the FGD system was essentially completed in February, 1979, a significant amount of work remained on the lime feed and waste processing facilities. Therefore, the costs presented here represent the actual expenditures incurred plus estimates for completion of the system.

Table IV-1 gives a summary of the capital investment for all three facilities. The total projected cost of $20.6 million includes actual expenditures reported through February 28, 1979 and the estimated capital required for completion. Approximately 80% of this total projected capital cost was expended through the end of February. Most of the remaining 20% is related to the waste processing plant.

A breakdown of capital investment by sub-system is given in Table IV-2. This table also provides information on the capital expenditures incurred through February 28, 1979 as a percent of the estimated total capital required for each facility.

The capital costs in Tables IV-1 and IV-2 have been reported on an "as-incurred plus estimate for completion" basis, and therefore do not represent a constant dollar value of the capital investment. The cash flow records kept by LG&E have been used to escalate the costs from the time of expenditure to June, 1979. The total capital investment for the dual alkali system (including all three systems) is $22.0 million in June, 1979 dollars.

TABLE IV-1

CAPITAL COSTS FOR THE DUAL ALKALI SYSTEM
AT CANE RUN UNIT NO. 6, LG&E

"As-Incurred Plus Estimate for Completion Basis"

MATERIAL COSTS:	
• FGD System	$10,093,200
• Lime Slurry Feed System	788,000
• Solid Waste Disposal System[a]	1,929,500
TOTAL MATERIAL COSTS	$12,810,700
ERECTION COSTS:	
• Direct Labor	$ 3,058,500
• Field Supervision[b]	337,200
• Construction Overhead	2,038,900
TOTAL ERECTION COSTS	$ 5,434,600
ENGINEERING COSTS:[b]	
• System Supplier's Engineering	$ 1,162,700
• Owner's Consultant Engineering	985,000
TOTAL ENGINEERING COSTS	$ 2,147,700
SPARE PARTS	203,900
TOTAL CAPITAL INVESTMENT	$20,596,900

[a]Battery limits: cake discharge from filters.

[b]Owner's engineering is included in field supervision.

TABLE IV-2

CAPITAL COST BREAKDOWN BY SUB-SYSTEM[a]

LOUISVILLE GAS & ELECTRIC CANE RUN UNIT NO. 6

Sub-System	Material Costs[b]	Engineering and Erection Costs	Total
FGD	10,256,200	6,206,800	16,463,000
	(91%)	(95%)	(93%)
Lime Slurry	800,000	416,200	1,216,200
	(69%)	(71%)	(70%)
Waste Disposal[c]	1,958,400	959,300	2,917,700
	(0%)	(0%)	(0%)
Total	13,014,600	7,582,300	20,596,000

[a]Numbers in parentheses represent expenditures incurred as of February 28, 1979 as percent of the estimated total costs.

[b]Includes spare parts at 1% of total costs.

[c]The estimates for waste disposal system are based on a contract awarded to IUCS to provide LG&E with the waste disposal facilities and estimated costs for the erection of the system.